



THE UNIVERSITY *of* EDINBURGH

## Edinburgh Research Explorer

### Predictive Processing of Coordination in CCG

**Citation for published version:**

Stanojevi, M, Hale, J & Steedman, M 2020, Predictive Processing of Coordination in CCG. in *Proceedings of the 33rd Annual CUNY Conference on Human Sentence Processing*. <<https://osf.io/4qh28/>>

**Link:**

[Link to publication record in Edinburgh Research Explorer](#)

**Document Version:**

Peer reviewed version

**Published In:**

Proceedings of the 33rd Annual CUNY Conference on Human Sentence Processing

**General rights**

Copyright for the publications made accessible via the Edinburgh Research Explorer is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

**Take down policy**

The University of Edinburgh has made every reasonable effort to ensure that Edinburgh Research Explorer content complies with UK legislation. If you believe that the public display of this file breaches copyright please contact [openaccess@ed.ac.uk](mailto:openaccess@ed.ac.uk) providing details, and we will remove access to the work immediately and investigate your claim.



## Predictive Processing of Coordination in CCG

Miloš Stanojević (University of Edinburgh\*), John Hale (University of Georgia), Mark Steedman (\*)  
m.stanojevic@ed.ac.uk

Human sentence processing is highly incremental at all levels, including semantic interpretations (Altmann & Kamide, 1999; Aoshima, Yoshida, & Phillips, 2009; Marslen-Wilson, 1973; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). Right adjuncts are interesting in this context because processing models often make adjunction a non-incremental operation, so that the structure they modify cannot be integrated with the prefix until the adjunct is complete. This observation holds of the left-corner approaches to generative grammar (Hale, 2014; Stanojević & Stabler, 2018) and of greedy shift-reduce approaches to parsing Combinatory Categorical Grammar (CCG, Steedman, 1989), making them appear inconsistent with psycholinguistic findings. Sturt and Lombardo (S&L, 2005) have shown that a greater degree of incrementality seems to be needed in processing coordinations as in Figure 1. Here the right conjunct can be interpreted as an instance of right-adjunction. S&L propose using the *adjoin* operation of *Tree-Adjoining Grammar* (TAG) (see also Demberg, Keller, and Koller (2013)) to explain this incrementality. However, for reasons elaborated below, alternative explanations in terms of other grammar formalisms are worth exploring.

In particular, no one has yet shown how to reconcile the result of S&L with CCG incremental parsing. We argue that the operations of tree *rotation* and *revealing* from Stanojević and Steedman (2019) are sufficient to explain the results of S&L (see also Pareschi and Steedman (1987) and Niv (1994)). The parser builds the structure as a left-branching CCG derivation (Figure 2a), which gets automatically *rotated* to be right branching (Figure 2b), making the VP available for modification by possible future right-adjunction. The rest of the derivation goes normally until “herself” is read, when there is a binding anomaly because of the gender-biased interpretation of the antecedent “the pilot”. This binding cannot be accomplished with standard CCG parsing, but a predictive phase of the parser can detect from the type  $((S \backslash NP) / PP) / NP$  of the verb “put” that there is a PP coming. In this predictive phase, a placeholder PP is made available to complete the right conjunct and attach it to the left conjunct using the *reveal* transition from Stanojević and Steedman (2019) as shown in Figure 3, allowing the bias-conflicting binding to disrupt processing, before returning to the standard phase of parsing to redo the same analysis when the actual PP is complete. The predictive behavior of verbs is supported by psycholinguistic experiments (Arai & Keller, 2013).

This CCG parsing approach bears a different relationship to linguistic theory than does the TAG approach of S&L and Demberg et al 2013. First, it obeys the Coordinate Structure Constraint (CSC). In order for TAG to respect CSC, the parser needs to use tree-unification (Sarkar & Joshi, 1996a) combined with lexical insertion. The addition of these operations to TAG makes the incremental TAG parser significantly more complex (Sarkar & Joshi, 1996b). Second, our approach conforms to the Strict Competence Hypothesis (SCH, Steedman, 1989) which states that the processor cannot build any structure that is not directly licensed by the competence grammar. Finally, the *reveal* operation from Stanojević and Steedman (2019) influences only the level of incrementality without changing the weak or strong generative capacity of CCG. Revealing combined with prediction addresses all the incrementality issues raised by Demberg (2012) and S&L.

When we consider S&L sentences, this CCG parsing model makes the same incrementality predictions as the S&L’s TAG model, but it does so using a different mechanism. Derivations presented by S&L do not use tree-unification although they should since they coordinate verbs that share the same subject. If we consider the correct derivations with tree-unification, in order to keep the TAG parser incremental the parser would either have to use a top-down strategy that predicts coordination schema in advance, an approach that is argued against by S&L as being implausible, or it would be a predictive parser of the sort that is proposed in our work.

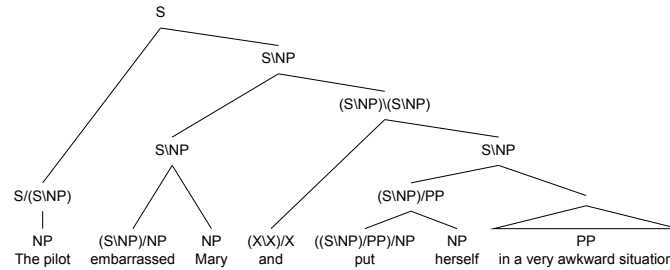


Figure 1: Full (non-incremental) derivation.

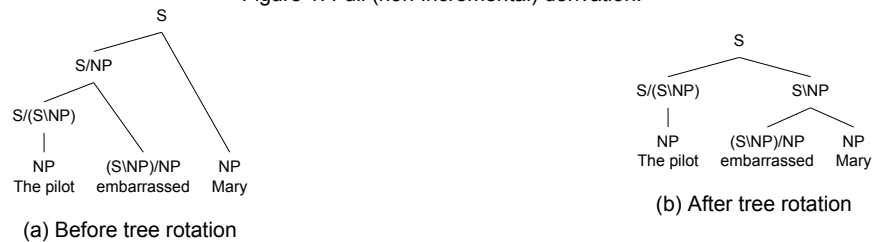


Figure 2: The effect of tree rotation on the left conjunct.

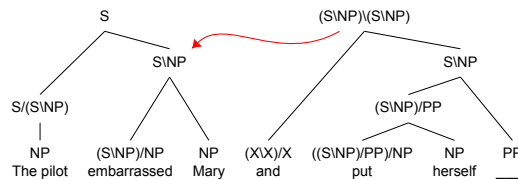


Figure 3: Attachment of the right conjunct with a hole.

- Altmann, G., & Kamide, Y. (1999). Incremental interpretation at verbs: Restricting the domain of subsequent reference.
- Aoshima, S., Yoshida, M., & Phillips, C. (2009). Incremental processing of coreference and binding in Japanese. *Syntax*.
- Arai, M., & Keller, F. (2013). The use of verb-specific information for prediction in sentence processing. *Language and Cognitive Processes*, 28, 525-560.
- Demberg, V. (2012). Incremental derivations in CCG. In *Proceedings of the 11th TAG+*.
- Demberg, V., Keller, F., & Koller, A. (2013). Incremental, predictive parsing with psycholinguistically motivated tree-adjoining grammar. *Computational Linguistics*.
- Hale, J. (2014). *Automaton theories of human sentence comprehension*. Stanford: CSLI.
- Marslen-Wilson, W. (1973). Linguistic structure and speech shadowing at very short latencies. *Nature*.
- Niv, M. (1994). A psycholinguistically motivated parser for CCG. In *Proceedings of the 32nd annual meeting on association for computational linguistics*.
- Pareschi, R., & Steedman, M. (1987). A Lazy Way to Chart-parse with Categorical Grammars. In *Proceedings of the 25th annual meeting on association for computational linguistics*.
- Sarkar, A., & Joshi, A. (1996a). Coordination in tree-adjoining grammars: Formalization and implementation. In *Proceedings of the international conference on computational linguistics*.
- Sarkar, A., & Joshi, A. (1996b). *Handling coordination in a tree adjoining grammar* (Tech. Rep.). Department of Computer and Information Science, University of Pennsylvania, Philadelphia, PA.
- Stanojević, M., & Stabler, E. (2018). A Sound and Complete Left-Corner Parsing for Minimalist Grammars. In *Proceedings of the Eight Workshop on Cognitive Aspects of Computational Language Learning and Processing*.
- Stanojević, M., & Steedman, M. (2019). CCG Parsing Algorithm with Incremental Tree Rotation. In *Proceedings of the 2019 conference of the NAACL, volume 1 (long papers)*.
- Steedman, M. (1989). Grammar, interpretation, and processing from the lexicon. In W. Marslen-Wilson (Ed.), *Lexical representation and process*. Cambridge, MA: MIT Press.
- Sturt, P., & Lombardo, V. (2005). Processing coordinated structures: Incrementality and connectedness. *Cognitive Science*, 29, 291-305.
- Tanenhaus, M. K., Spivey-Knowlton, M. J., Eberhard, K. M., & Sedivy, J. C. (1995). Integration of visual and linguistic information in spoken language comprehension. *Science*.